

# Nuclear Track Detectors for Particle Searches

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## Abstract

In this paper we report a search for intermediate mass magnetic monopoles and nuclearites using CR39 and Makrofol Nuclear Track Detectors (NTDs) of the SLIM large area experiment, 440  $m^2$  exposed at the high altitude laboratory of Chacaltaya (Bolivia) and about 100  $m^2$  at Koksil, Himalaya (Pakistan). We discuss the new chemical etching and improved analysis of the SLIM CR39 sheets. Preliminary limits are based on 316  $m^2$  of CR39 NTDs exposed for 3.9 y.

## 1 Introduction

Grand Unified Theories (GUT) of the strong and electroweak interactions predict the existence of magnetic monopoles (MMs) of large mass ( $10^{16}$  -  $10^{18}$  GeV/ $c^2$ ), produced in the early Universe. The MACRO experiment has set the best limits on GUT MMs for  $4 \times 10^{-5} < \beta < 1$ ,  $\beta = v/c$  [1-2].

Intermediate Mass Magnetic Monopoles (IMMs) may have been produced in later phase transitions in the Early Universe; IMMs with masses  $10^7 < m_M < 10^{13}$  GeV and  $g > g_D$  could be present in the cosmic radiation and could be accelerated to relativistic velocities in one coherent domain of the galactic magnetic field [3-4]. Thus one may look for  $\beta \geq 0.1$ , heavily ionizing IMMs.

We used CR39 nuclear track detectors (NTDs) for a variety of studies: searches for magnetic monopoles and nuclearites, determination of fragmentation cross-sections, search for nuclear fragments with fractional charges, measurement of the composition of primary cosmic rays [5-6].

The main aim of the present work is the determination of the optimal etching conditions to achieve the best surface quality and to reduce the number of background tracks in CR39 and Makrofol NTDs used in the SLIM experiment.

## 2 Experimental

The SLIM experiment planned for the search of IMMs and Strange Quark Matter (SQM) is based on 440  $m^2$  of NTDs installed at the Chacaltaya high altitude lab. (5230 m a.s.l.) since 2001 [7]. Another 100  $m^2$  of NTDs were installed at Koksil, Himalaya (Pakistan, 4270 m a.s.l.) since 2002. The radon activity and the flux of cosmic ray neutrons were measured at Chacaltaya [8].

The SLIM basic unit is a “wagon” composed of 3 layers of 1.4 mm thick CR39, 3 layers of 500  $\mu m$  Makrofol, 2 layers of 250  $\mu m$  lexan sheets and an aluminium absorber of 1 mm thick, see Fig. 1.

Extensive test studies were made in order to improve the etching procedures of CR39 and Makrofol NTDs, and to improve the scanning efficiency and analysis procedures. In this note we discuss the etching procedures for the SLIM CR39 and Makrofol NTDs.

The CR39 foils from SLIM modules exposed to cosmic rays and to 1 A GeV  $Fe^{26+}$  ions were originally etched without alcohol. We found several background tracks of 10-17  $\mu m$  range due to carbon, oxygen and proton recoils produced in the interactions of ambient neutrons; see Figure 2(a, b): the surface quality of both sheets was poor. In these conditions, it would be difficult to scan the detectors. In order to improve the surface quality and to eliminate the recoil tracks we etched the CR39 sheets with 8N KOH + 1.5% ethyl alcohol at 75 °C for 30 hr (see Figure 2(c, d)). The surface quality of the etched SLIM CR39 sheets improved and most of the recoil tracks were removed. Moreover the detector is transparent and scanning is easier. The tracks of the relativistic iron ions and their fragments have sharp contours and can be easily measured with the automatic image analyzer system "ELBEK". The threshold of the detector increased to  $Z/\beta \sim 17$ .

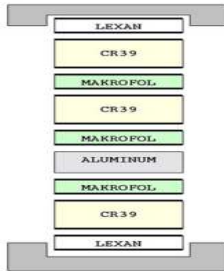


Figure 1: Sketch of a SLIM "wagon", sealed in an aluminium plastic bag.

CR39 "strong etching conditions" are now used for the first (top) CR39 sheet in each SLIM module (see Fig. 1), in order to produce "large tracks", easier to detect during scanning. "Soft etching conditions" (6N NaOH + 1% Ethyl alcohol at 70 °C for 40 hours) are applied to the other CR39 layers in a module [9], if a candidate track is found in the first layer. Soft etching allows more reliable measurements of the restricted energy loss (REL) and of the direction of the incident particle.

The Makrofol detectors are etched in 6N KOH + 20% ethyl alcohol at 50 °C [10-11].

### 3 Calibration

The CR39 and Makrofol detectors were calibrated with 158 A GeV  $In^{49+}$  and  $Pb^{82+}$  ions at the CERN SPS and 1 A GeV  $Fe^{26+}$  ions at the BNL AGS [11]. The base areas of the "post-etched cones" were measured with an automatic image analyzer system. Fig. 3 shows the average base area distribution of 158 A GeV  $In^{49+}$  ions and their fragments, the averages were made on two front faces of CR39 sheets. With the above mentioned etching, the peaks are well separated from  $Z/\beta = 7$  to 45 and charge can be assigned to each individual peak.

The "strong" etching conditions for CR39 allow the detection of MMs with one unit Dirac charge ( $g=g_D$ ), for  $\beta$  around  $10^{-4}$  and for  $\beta > 10^{-2}$ , the whole  $\beta$ -range of  $4 \times 10^{-5} < \beta < 1$  for MMs with  $g \geq 2 g_D$ , for dyons and for nuclearites. The Makrofol is useful for the search for fast MMs. CR39 and Makrofol can detect nuclearites with  $\beta \geq 10^{-3}$ .

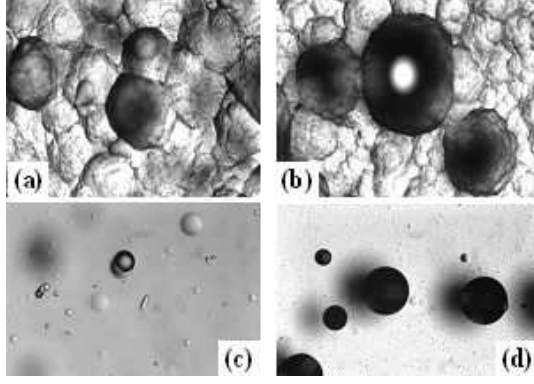


Figure 2: (a) SLIM CR39 sheet, (b) tracks of 1 A GeV  $Fe^{26+}$  ions and their fragments in CR39 using 8N NaOH 90 °C for 48h without alcohol, (c) SLIM CR39 sheet and (d) the tracks of 1 A GeV  $Fe^{26+}$  ions and their fragments in CR39 with “strong” etching with 1.5% ethyl alcohol at 75 °C, ( $G_{tot.} = 20x$ ).

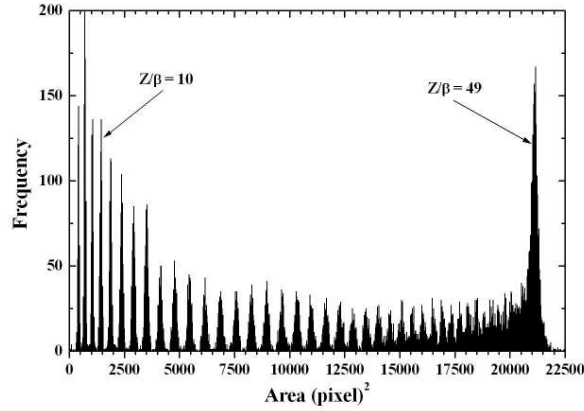


Figure 3: Base area distribution of etched cones in CR39 from 158 A GeV  $In^{49+}$  ions and their fragments (averages of 2 front face measurements)

## 4 Results and Discussion

The top CR39 layer (see Fig. 1) of each wagon was chemically treated with our improved “strong” etching conditions with alcohol to reduce the thickness of CR39 sheets from 1400  $\mu m$  to 900  $\mu m$  and to make large tracks. The etched CR39 sheets were transparent and with low background. The sheets were scanned with stereomicroscopes searching for passing tracks, which form a double cone, or through holes.

In order to compute the p-values and incident angles  $\theta$  for the front and backsides, the track major and minor axes are also measured. Finally, a track is defined as a “candidate” if p and  $\theta$  on the front and backsides are equal to within 15%. In the presence of a candidate, the lowermost CR39 layer was etched in “soft conditions”, and an accurate scan was performed with an optical microscope at high magnification. Up to now no two-fold coincidences or through holes were observed.

## 5 Conclusions

We analyzed an area of 316  $m^2$  of SLIM CR39 sheets exposed for 3.9y at the Chacaltaya high altitude lab. No candidate was observed; the 90% CL upper flux limits for downgoing IMMs

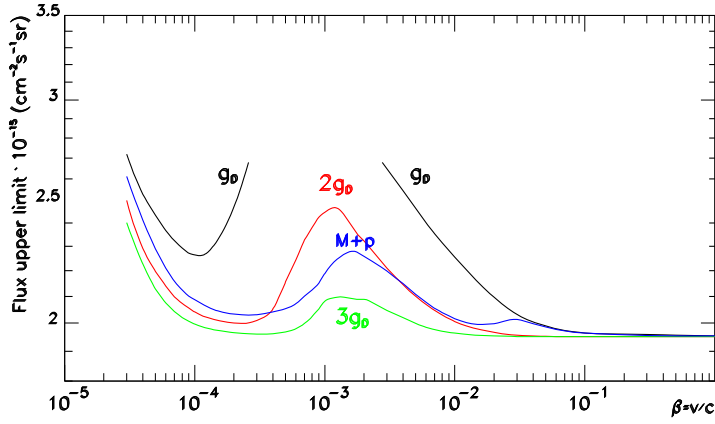


Figure 4: 90% C.L. flux upper limits for downgoing intermediate mass magnetic monopoles with  $g = g_D, 2g_D, 3g_D$  and  $M+p$ .

with  $g = g_D, 2g_D, 3g_D$  and  $M+p$  are plotted in Fig. 4 versus  $\beta$ .

Intermediate mass nuclearites lose more energy than  $g = g_D$  magnetic monopoles; thus the limit is at the level of the MM limit for  $\beta > 0.1$  ( $\Phi < 1.89 \times 10^{-15} \text{ cm}^2 \text{ s}^{-1} \text{ sr}^{-1}$ ). A special search was made for very light nuclearites; since we found no candidate the limit is as indicated for IMMs at high  $\beta$ .

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